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PRINCIPAL INVESTIGATOR: Hsiao-Ming Lu, Ph.D.

CONTRACTING ORGANIZATION: Dana-Farber Cancer Institute
Boston, Massachusetts 02115

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Hsiao-Ming Lu, Ph.D.

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Dana-Farber Cancer Institute
Boston, Massachusetts 02115

E-Mail: hmlu@lroc.harvard.edu

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13. ABSTRACT *(Maximum 200 Words)* The first year of this contract concentrated on the software and hardware developments for the building of the patient position/posture monitoring system, which is the core of the breath-holding treatment technique. These mainly involved understanding the commercial infrared camera system (POLARIS), the development of the software interface between the camera system and the host computer for data transfer and for detection parameter control, the development of a software program to calibrate the camera system to the coordinate system of the CT-simulator and linear accelerator treatment rooms, the development of a software program to track the coordinates of the markers placed on the patients to monitor the patient body configuration. A prototype patient position monitoring system has been completed. In addition, experiments have been conducted to evaluate the accuracy of a hemispherical marker to be used to monitor the position of certain points on the patients. Efforts have also been spent to develop a planning tool that is essential in determining if a particular patient could benefit from a breath-holding treatment. Overall the project has basically completed all the goals planned for the first year.

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IV. INTRODUCTION

1. CLICNICAL PROBLEM, BACKGROUND AND HYPOSHTESIS

Grant DAMD17-99-1-9084 supports the development of a new radiation therapy treatment technique for left-sided breast cancer patients. The new technique uses simple respiratory maneuvers to reduce radiation to cardiac tissues to avoid possible late cardiac effects. Specifically the grant supports the development and testing of a patient position monitoring system, which will ensure that the radiation treatment is delivered accurately and only when the patient is at the optimal body configuration during the respiratory maneuvers. The grant also supports the development of a treatment planning software that will promptly evaluate quantitatively the benefit of the new treatment technique for a specific patient.

Radiation therapy (RT) plays an important role in patients with early-stage breast cancer both for a) improved quality of life through its use with lumpectomy in providing breast-conserving local therapy and b) possibly improved survival when used as comprehensive local-regional treatment in conjunction with systemic therapy[1].

An important caveat in considering the effects of local radiation therapy is its toxicity; early reports demonstrated that post-mastectomy RT was associated with an increased cardiac mortality from outdated RT techniques[2-10]. With modern RT techniques, e.g., CT-simulation, cardiac volumes can be delineated more accurately geometrically relative to the radiation field and treatment plans can be more optimized to reduce the radiation to the heart. However, in many cases, the radiation beam still has to traverse a non-negligible portion of the heart in order to treat all of the breast tissue and the concave chestwall to eradicate the residual disease. There is great concern worldwide about the possible late cardiac effects of RT when used in conjunction with cardiotoxic adjuvant chemotherapy. As the incidence of breast cancer increases and the age of the patient population decreases, the issue of late cardiac toxicity will become more important and it is imperative that we search for safer techniques to deliver the radiation treatment.

In the current technique of RT, the patient breathes normally while receiving the radiation treatment. In a recent study of a group of patients, we found that holding breath after a deep inspiration can significantly reduce the cardiac volume in the tangent treatment fields. For many patients, deep inspiration can push cardiac tissues completely out of the treatment fields.

The clinical rational and hypothesis for this work is that we can develop a treatment technique that delivers the radiation only when the patients hold their breath after a deep inspiration. In a typical first-course breast cancer RT treatment, the radiation dose is given by 22-30 fractions over the period of 4.5 - 6 weeks. On each day, the treatment uses two tangent fields, the medial tangent field and the lateral tangent field, to deliver the radiation. For each beam, the actual time receiving the radiation is about 20-30 seconds, depending on the prescribed dose and/or the patient's anatomy. From our experience with the breath-holding study mentioned above, we found that patients can hold their breath for 20 seconds without any difficulty. If we use 10 seconds of the 15-20 seconds breath-holding duration to deliver the radiation, it only requires 2-3 breath-holding cycles to deliver the total radiation required for each beam. Fig. 4 illustrates the treatment time sequence for one breath-holding cycle.

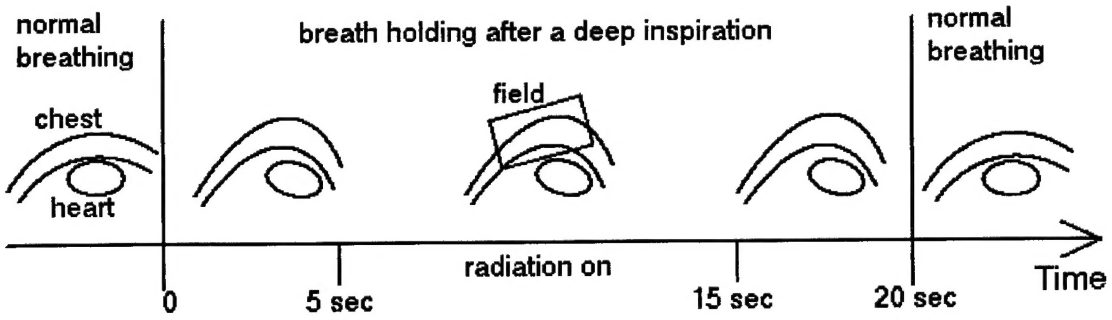


Fig. 1. Treatment time sequence for one breath-holding cycle.

2. SPECIFIC RESEARCH OBJECTIVES

2.1 Patient position monitoring system

In order for the patient to receive the radiation treatment to the exact anatomical location as planned, it is important that the patient's body position is the same from the treatment planning facility, i.e., the CT-simulator, to the treatment linear accelerator, from one breath-holding cycle to the next, from one treatment beam configuration to another beam, and from one day to another day throughout the whole treatment course of 22-30 days. This requires a monitoring system that can instantaneously track the patient's breath-holding state. Such a system can be developed using a computer interfacing with a three-dimensional (3D) digitization device, for example, the POLARIS system that uses infrared light to track instantaneously the position of infrared reflective markers in space. By placing these markers on the patient's chest and tracking the three-dimensional coordinates of the spheres, one can monitor the motion of any point on the patient's chest with sub-millimeter accuracy.

The development of this patient position/posture monitoring system involves 1) the development of a software interface between the POLARIS system and the host computer, 2) the development of tools for capturing patient body configuration information, 3) the testing of the accuracy and active volume of the POLARIS system and the reflective markers in CT simulator and linear accelerator treatment facilities, 4) the development of software for the calibration of the tracking system to the coordinate system of the facilities (CT-simulation/treatment linear accelerator), 5) the development of the a software for tracking markers placed on patients and evaluating if the patient entered the breath holding configuration for treatment, 6) the testing of tracking system by phantoms, and finally 7) the testing of the system on real patients.

2.2 Special functions in treatment planning software

The breath-holding treatment method requires special treatment planning functions that are not available in current commercial CT-simulation/treatment planning software systems. These include 1) the accurate and rapid calculation of the cardiac volume in the field at the CT simulation for both the normal-breathing and breath-holding configuration to determine if the breath-holding treatment technique is necessary for a specific patient, 2) automated or semi-automated field placement procedure for tangential fields with full field matching to allow the planner to rapidly evaluate different treatment geometries, 3) accurate dosimetric corrections for the extremely low lung density due to deep inspiration, 4) convenient interface with the patient position/posture monitoring system.

V. BODY OF ANNUAL REPORT

OVERALL PROGRESS

For the first year, research activities are planned mainly along two separate lines (see approved Statement of Work). The first involves software and hardware developments for building the patient position monitoring system. This will produce a prototype of the patient position monitoring system so that it can be tested on the phantom. These tasks have all been completed on time and a prototype system has been developed. In addition to these planned activities, other works have also been performed around issues occurred during the development process. One of these involves the evaluation of the accuracy of a new type of reflective marker, shaped as a hemisphere, as opposed to the spherical-shaped marker considered in the original plan. The hemisphere markers can be better in monitoring the patient body configuration, since it can give the exact coordinates of the point on the patient skin.

The other line of work involves the development of treatment planning functions/tools that is essential for the use of the breath-holding treatment technique. These include the prompt calculation of the cardiac volumes in the field at the time of CT-simulation, so that the benefit of the breath-holding treatment technique can be quantitatively evaluated for a specific patient. Also important is the function to automate or semi-automate the placement of the tangential fields for an optimal beam geometry in terms of minimizing the cardiac and lung volumes in the field. It is essential that functions can be performed rapidly at the time of simulation, since for some patients, the current treatment technique of normal breathing may work just as well, and there is no need to pursue the breath-holding treatment with additional work and unnecessary CT scans.

Originally, we plan to implement these special functions in an existing CT-simulation software. However, we could not find a commercial CT-simulation software company that is willing to collaborate on this. As a result, we had to develop an independent software tool (Breast Simulation Tool). This tool can work hand in hand with a CT-simulation software (Advantage-Sim, General Electric) and perform the essential function of computing the cardiac volume in the field and placing the tangent fields semi-automatically. It also has the function to capture the coordinates of marker points from the CT-scans. These coordinates will be used in the patient position monitoring system. Although less than ideal, it is, however, a workable system and has all the functions specified in the original plan.

SPECIFIC PROGRESS

Patient position monitoring system

a) A software interface between the infrared tracking system (POLARIS) and the host computer has been developed. This allows the captured data by the infrared camera to be sent from the camera system to a program running on a PC computer. It also allows the program to send command from the computer to the POLARIS system to change operating parameters. The code is developed as a Visual Basic 6.0 module.

b) A software program has been developed to test the accuracy and working volume of the camera system in the simulation and treatment room. (Fig. 2) By capturing the coordinates of the markers and compare them with known values, the program allows one to measure the accuracy of the POLARIS system, as well as to monitor the calibration of the camera coordinate axes relative to the room coordinate system at the CT-simulation and linear accelerator rooms.

c) A POLARIS camera system has been installed in a CT simulation room (Fig. 3).

d) A software program has been developed to calibrate the camera coordinate system relative to the coordinate system of CT-simulation and linear accelerator treatment room (Fig. 4). Basically the program established the coordinate transformation from the camera system to the room system to be used by the patient position monitoring system. It also provides a tool for checking the calibration of the camera system.

e) The accuracy of the hemispherical markers has been studied (Fig. 5-6). Particularly, experiment has been conducted to measure the accuracy of the as a function of surface inclination from the axis of the camera. Fig. 7 illustrates the experimental setup. Fig. 8 shows the error in coordinates. This shows that if the normal direction of the patient surface to be monitored differs from the axis of the camera by too much, substantial error could be generated in the direction perpendicular to the surface. This may result some limitations of the use of this kind of marker or limitations regarding the way the patient can be positioned. (For example, this may require that some patients be placed on a high angle board so that their chest area surface are not so much away from the axis of the camera.)

f) A software program has been developed to organize the geometric information for a specific patient, e.g., the treatment field geometry, the position of the tattooed points, and the points to be monitor by the infrared camera system, etc., (Fig. 9). This program will allow one to assemble all the information from different sources, e.g., CT-simulation software, patient monitoring system in the CT-simulator, etc., together to produce a file that will be used by the patient monitoring system in the treatment room.

g) A software program has been developed monitor the positions of the markers on the patient at the time of treatment (Fig. 10). The program can load the file produced by the patient information organizer (f). The points monitored are divided into two groups: the patient posture control points and the field dependent points. The former consists points that are sensitive to the genera posture of the patient. With these points, the patient's body configuration is closely monitored. The second group contains points that are derived from the designed treatment fields, i.e., projections of treatment field borders on skin. By aligning these points with the treatment fields, as view through the beam's eye view, one can be sure that the patient is indeed in the correct configuration to received the planned treatment.

Special treatment planning tool for breast cancer treatment

Breast simulation tool (BST) works hand in hand with the CT-simulation software Advantage-Sim (General Electric). It can rapidly calculate the lung and heart volume in the tangent field. It also generate tangent field pairs based on the input of a few clinically relevant points, e.g., medial field border, lateral field border, etc., entered simply by a mouse click on the transverse CT display. Then the program can automatically produce a macro file that can in turn be used the CT-simulation software to automatically setup the tangent field pairs. Fig. 11 shows the breast simulation panel with the volume of lung and heart in the field. Fig. 12 shows the operator environment for CT-simulation using breast simulation tool.

Fig. 2. User interface for program to evaluate the accuracy of tracking infrared markers.

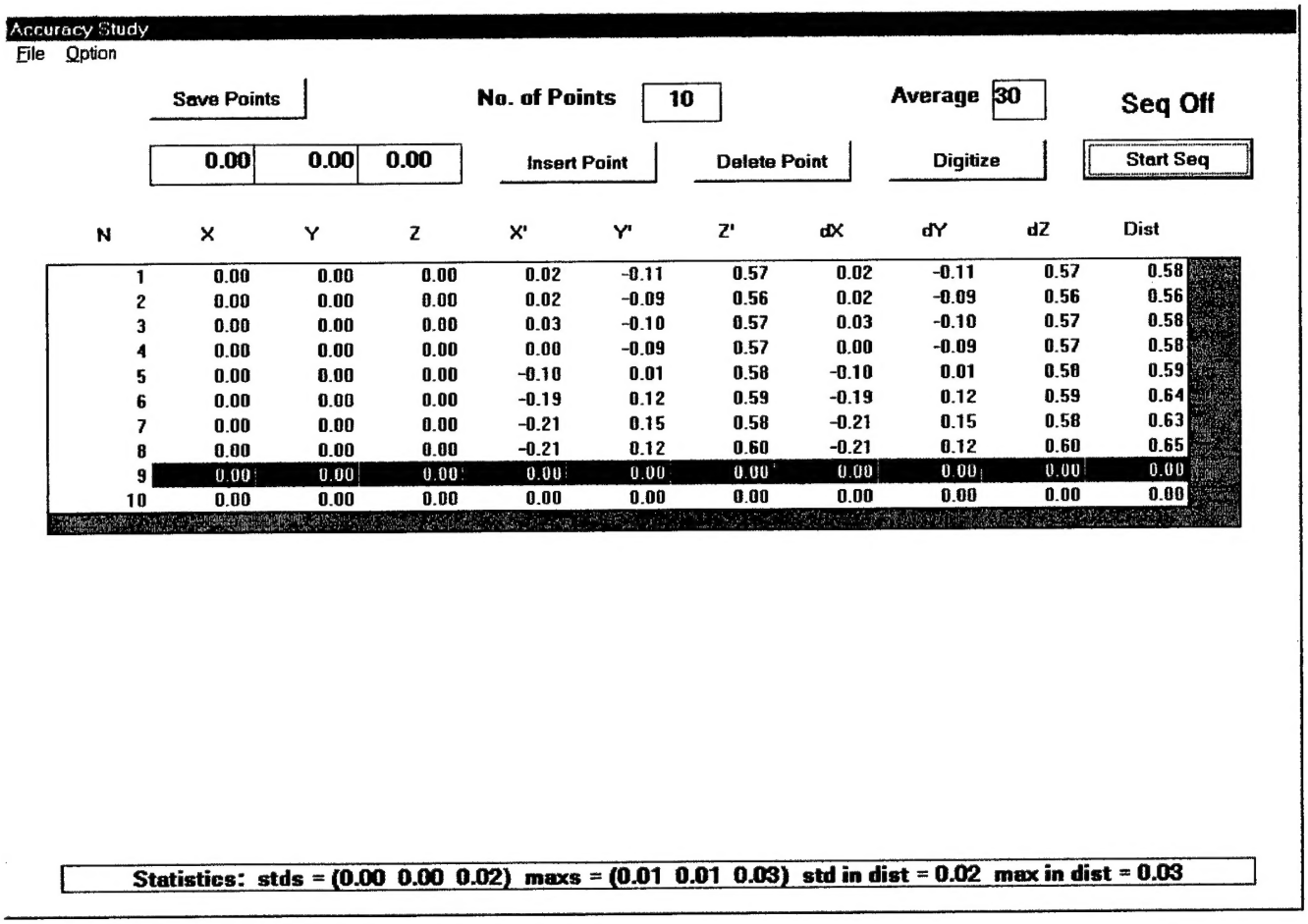
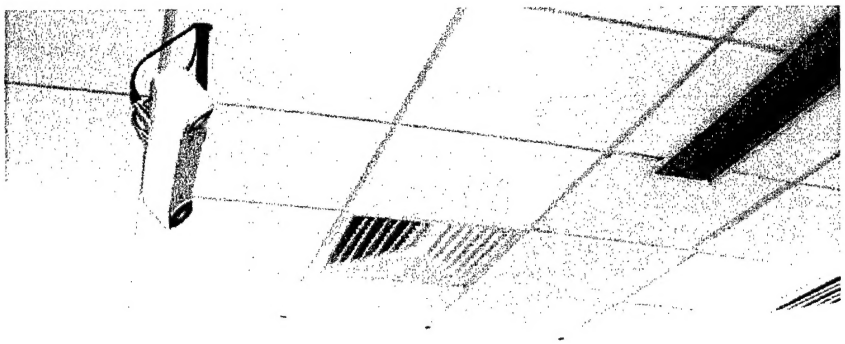


Fig. 3. System installation in CT-simulation room. The POLARIS camera is fixed on the ceiling. A breast phantom with a few hemisphere reflective markers is placed on the CT table. The host computer is

also shown.



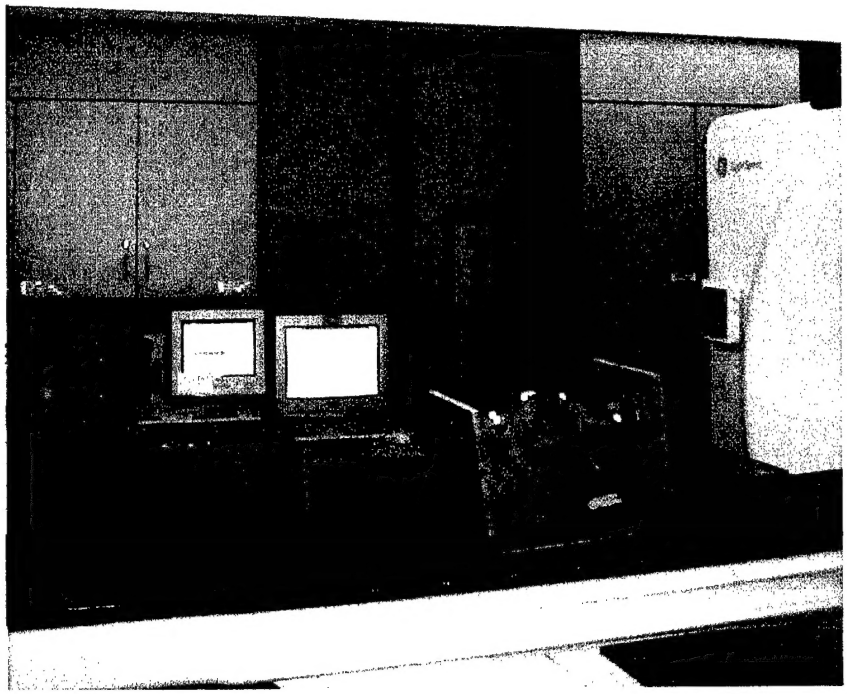


Fig. 4. User interface for calibrating the coordinate system of the POLARIS camera system the room coordinate system of the CT-simulator or the treatment linear accelerator.

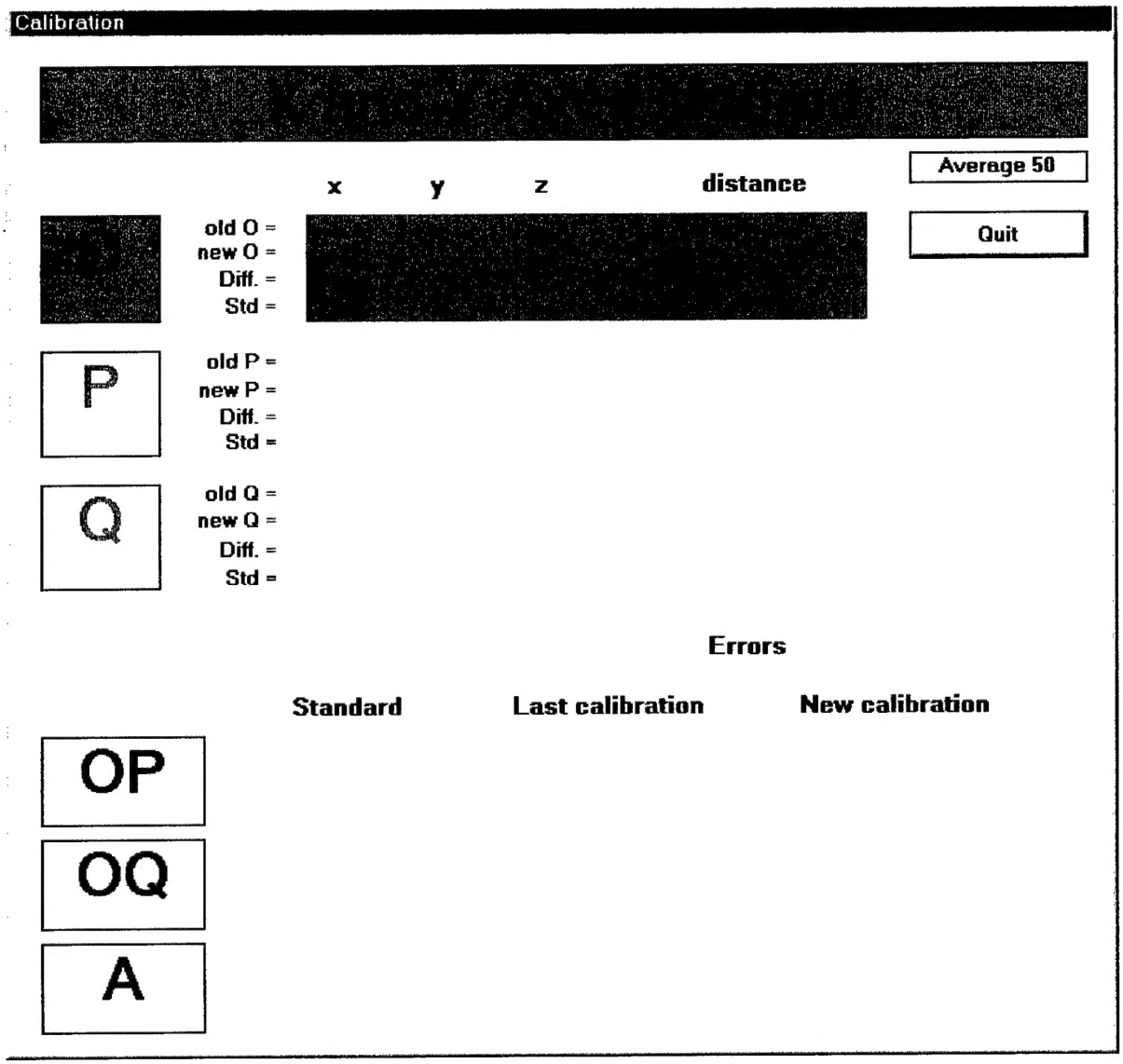


Fig. 5. CT reconstruction of the phantom surface with hemisphere reflective markers.

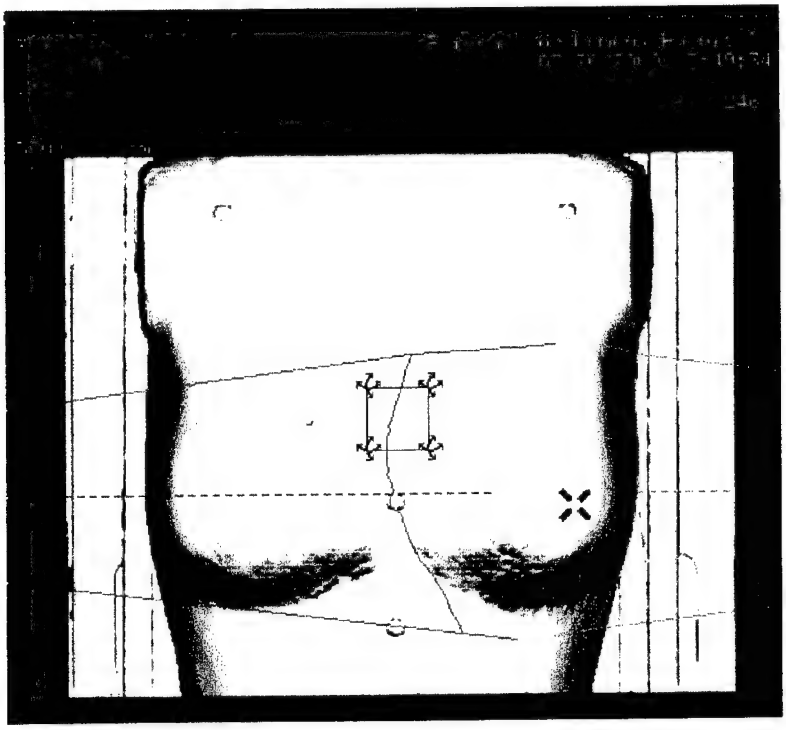


Fig. 6. Transverse view of the hemispherical marker. By placing a lead bee-bee at the center of the hemisphere, we can obtain the coordinate of the points to be monitored in the CT and compare it with the coordinates captured by the infrared system.

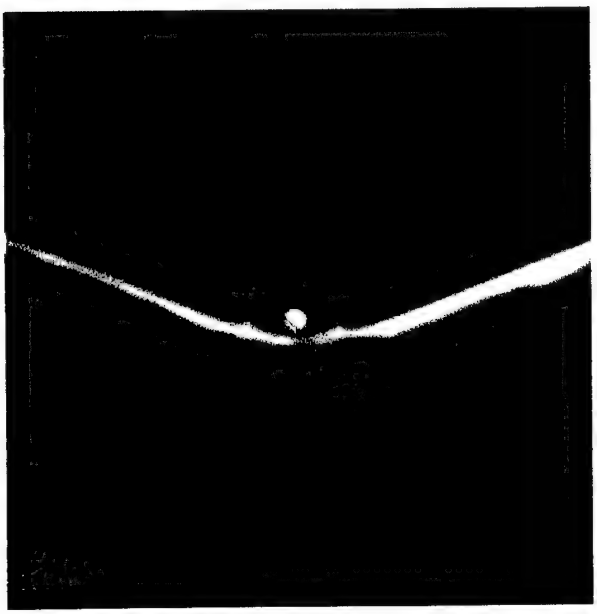


Fig. 7. Experimental setup for measuring the accuracy of the hemisphere marker as a function of the surface inclination from the camera axis.

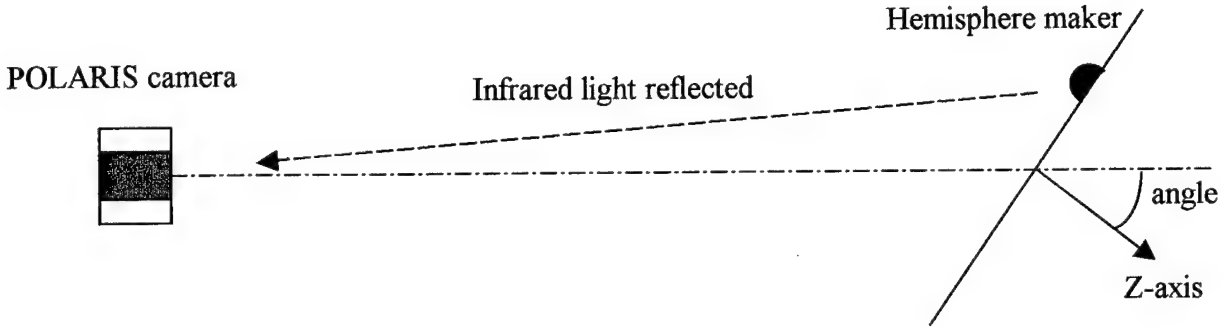


Fig. 8. Error in marker coordinates as a function of the surface inclination.

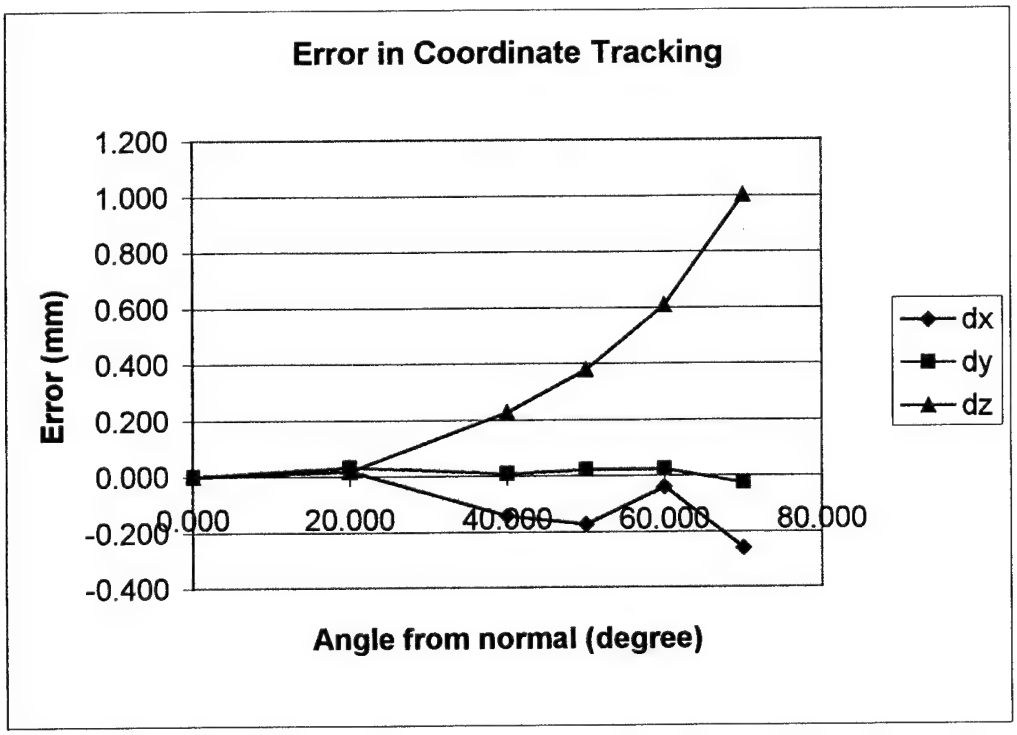


Fig. 9. Patient information organizer. It contains the treatment fields (left area), the list of field border tattoos in the beam's eye view (middle area), and the control points including patient posture control point, as well as field related points.

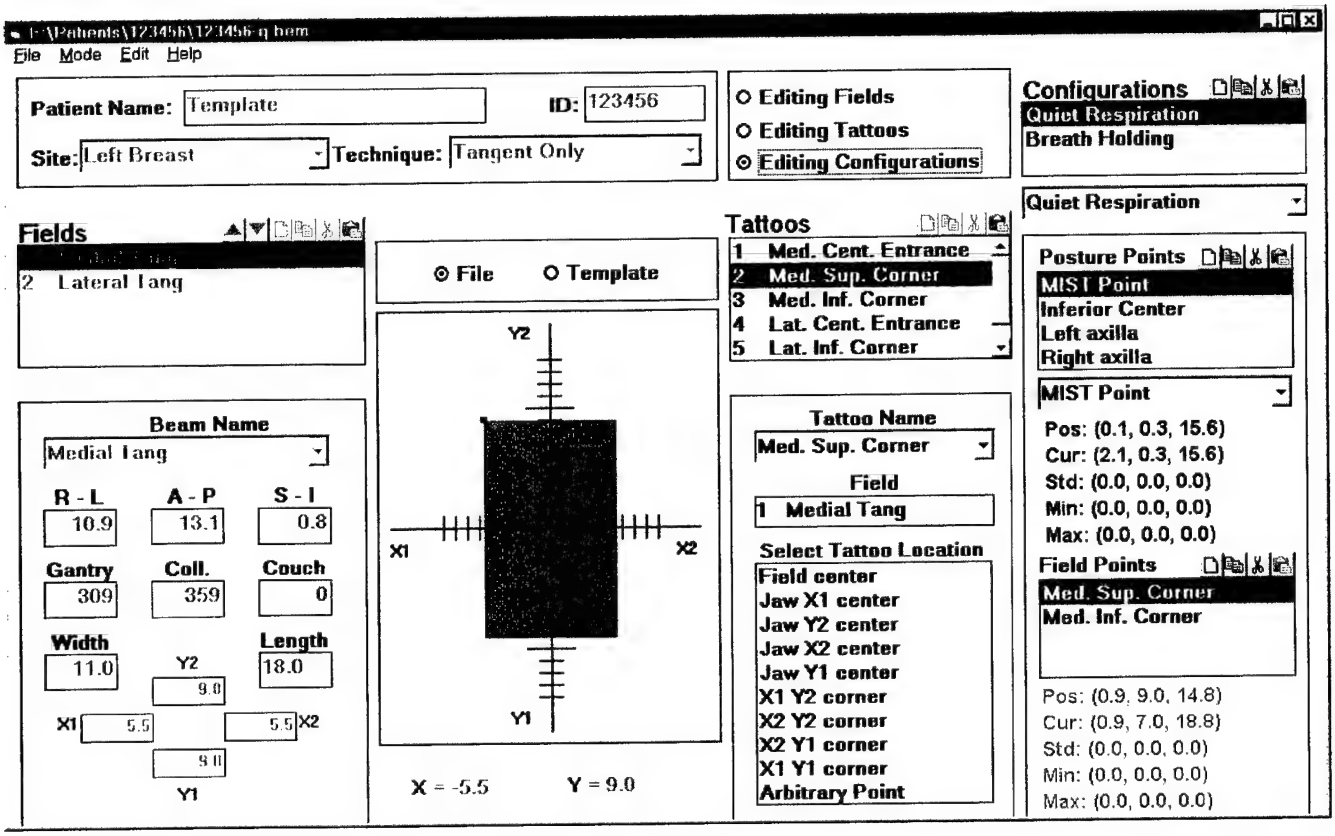


Fig. 10. Patient position monitoring system. This view shows the moment when all the control points on the patient (circles in display) match with the expected values (crosses in display). The left upper quadrant shows the beam's eye view and the matching of the field border projections. The other quadrant shows the orthogonal views of the control points. The green lights indicate that the patient's body entered the exact configuration to receive the treatment.

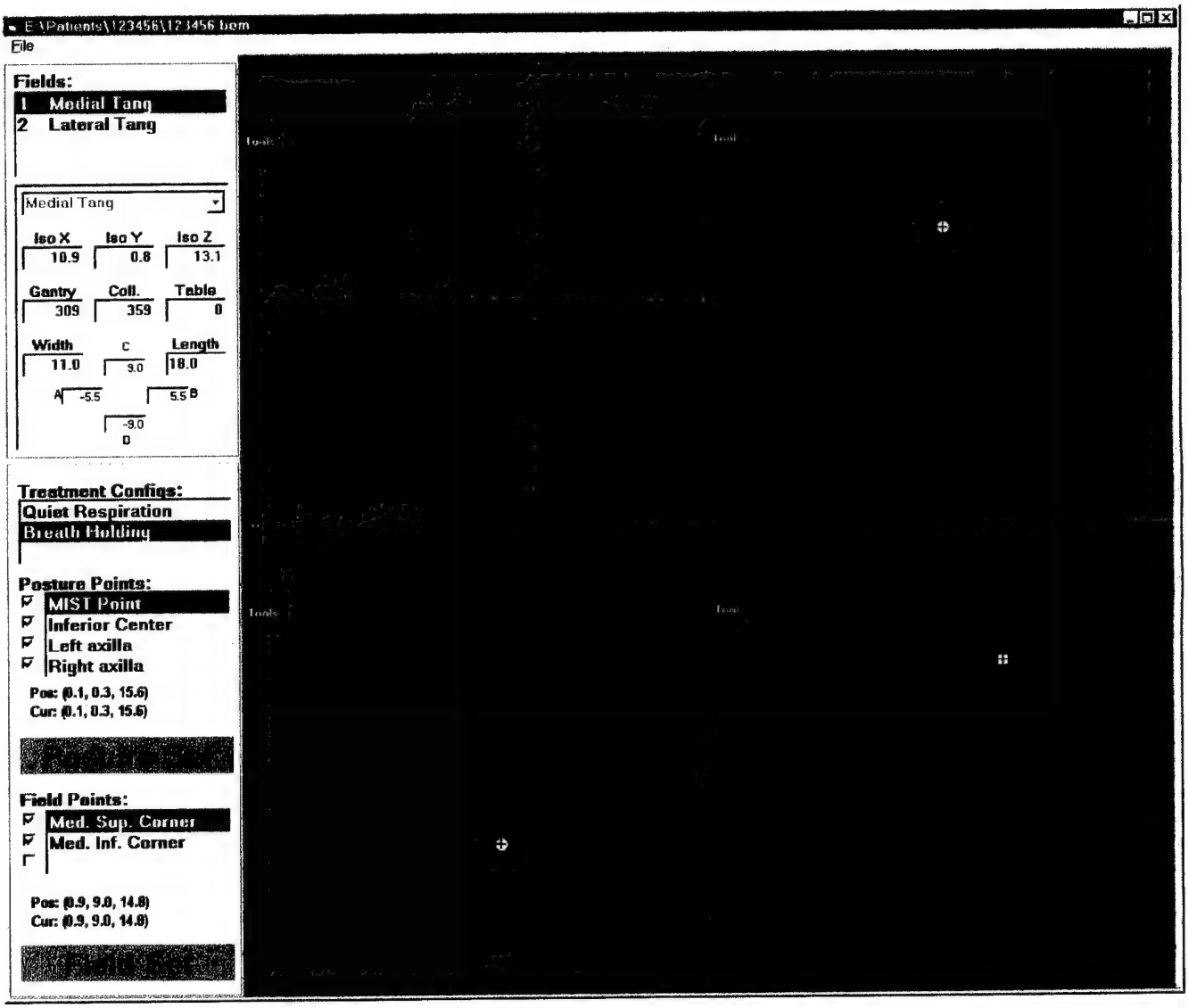


Fig. 11. Breast simulation tool. It shows the volume of lung and heart included in the tangential field pair.

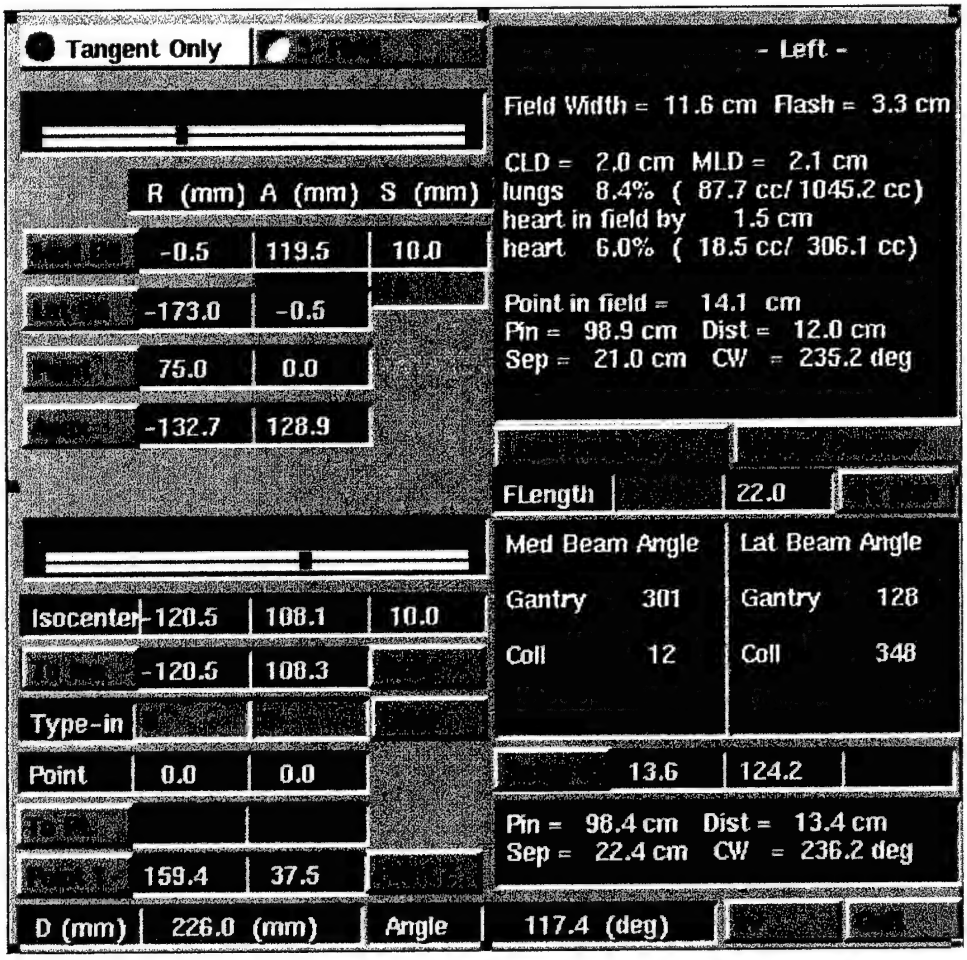
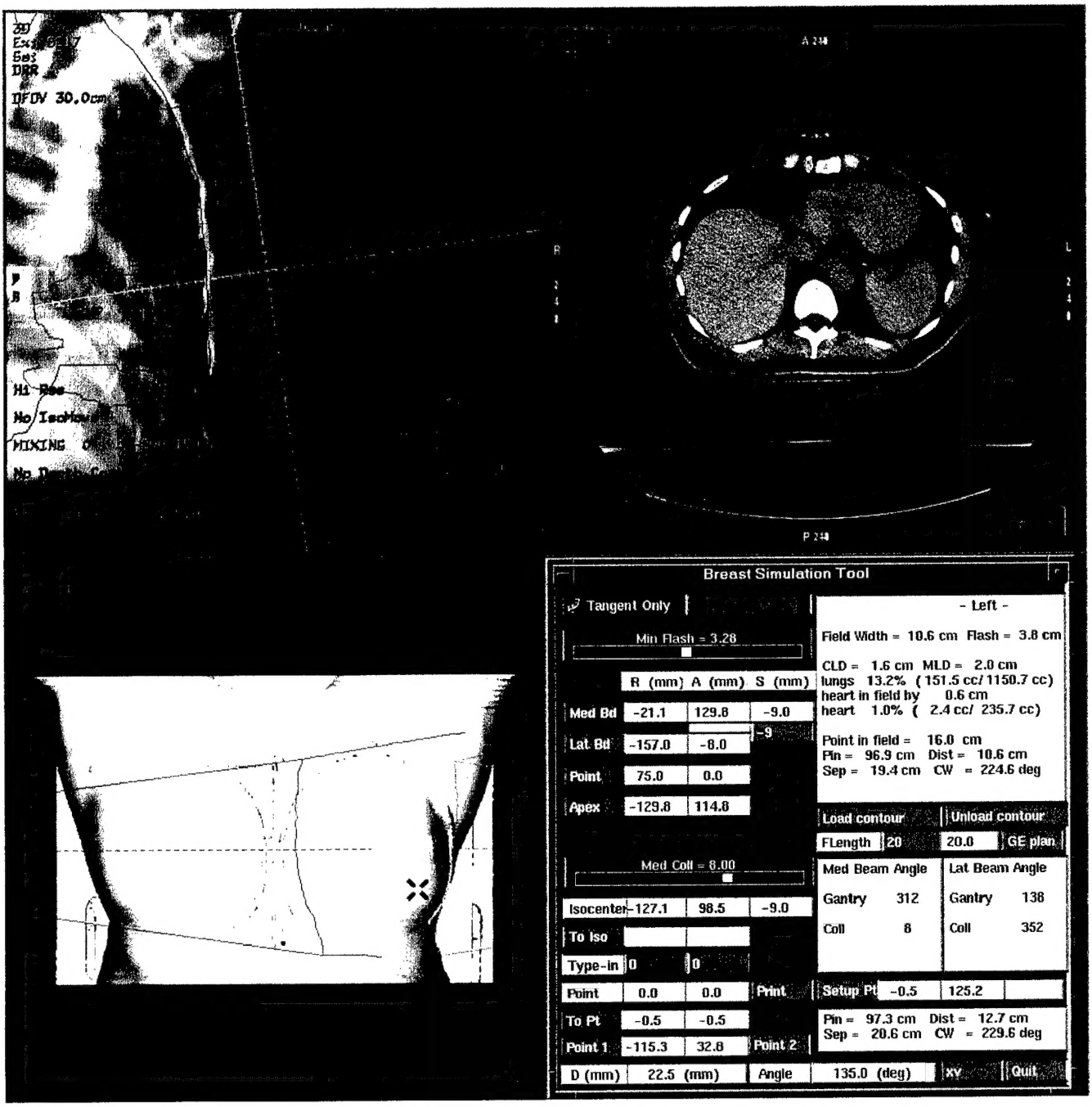


Fig. 12. User environment during CT-simulation of breast cancer treatment using breast simulation tool.



VI. KEY RESEARCH ACCOMPLISHMENTS

A prototype patient position monitoring system using infrared camera system (POLARIS) and reflective markers placed on patient body surface.

A software tool for CT-simulation of breast cancer treatment

VII. REPORTABLE OUTCOMES

A patient position monitoring system for radiation therapy treatment of breast cancer
By Hsiao-Ming Lu at the AAPM 2000 Annual Meeting, July, 2000, Chicago.

Abstract attached (Appendix A).

VIII. CONCLUSIONS

The main goal for the first year is to produce a prototype of the patient position monitoring system so that phantom testing and patient testing can be performed in the second year. Basically, this goal has been accomplished. The remaining problems include more evaluation of the hemispherical markers, their accuracy and convenient use on patient, as well as more work on better algorithms in the patient monitoring software.

In the second year, while continuing on the improvement of the software and hardware of the patient monitoring system, we will begin to install the system at the linear accelerator and proceed with phantom testing. Upon the satisfactory results of the phantom testing, non-invasive patient testing will begin.

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X. APPENDIX A.

Abstract for presentation at AAPM Annual meeting, July 2000, Chicago.

A patient position monitoring system for radiation therapy treatment of breast cancer

Hsiao-Ming Lu, Ph.D.

We have developed a patient position monitoring system specifically for breast irradiation using the breath-holding technique. Breath-holding (15-20 seconds) after a deep inspiration can substantially reduce the cardiac volume included in the tangential fields and thus reduces the possible late cardiac toxicity that has raised wide concerns particularly when cardiotoxic chemotherapy is also used. The system consists of a window-based software application interfacing with an infrared camera system that can track three-dimensional positions of infrared reflective markers with sub-millimeter accuracy. When such markers are placed on the patient's chest at points that control the patient's body posture as well as its position relative to the planned radiation fields, the system can accurately and instantaneously monitor the patient's body configuration throughout the breath holding cycle. Only when the patient fully reproduces the same breath holding configuration for which the treatment fields are designed, the system will issue a signal to the operator to turn on the radiation beam. While the treatment is proceeding, the system continues to monitor the patient and will interrupt the treatment if the body configuration changes beyond a specified tolerance. With the system, the patient is guaranteed to be in the same body configuration from CT-simulation to treatment, from field to field, from fraction to fraction throughout the whole treatment course, and thus receive the full benefits of the breath-holding treatment technique.